The interesting linkages for the suspension of the great bell in the cathedral of Metz

Denis Roegel

The interesting linkages for the suspension of the great bell in the cathedral of Metz

Denis Roegel*

13 May 2016

Abstract

This article studies the historiography of the suspension of the great bell of the cathedral of Metz and provides new insight in these interesting linkages.

1 Introduction

The cathedral of Metz (France) contains a large bell known as the *Mutte*, because it was used to call on the *meute* (crowd). This bell and its tower have recently been restored, and, during the last years, there has been a renewed interest in one of it features, namely its suspension.

In this article, we give an overview of what is known about this construction, we correct a few historical errors, and expand on the analysis of the linkages associated to the suspension.

2 A brief overview of the historiography of the suspension

The recent history takes its roots in Ladislao Reti's famed posthumous *Unknown Leonardo* (1974) [19], which gave to a large audience an overview of the breadth of Leonardo da Vinci's inventivity. This was not the first

*Denis Roegel, LORIA, BP 239, 54506 Vandœuvre-lès-Nancy cedex, roegel@loria.fr.

book on Leonardo, of course, but earlier publications, including the monumental facsimile of the *Codex Atlanticus* published at the end of the 19th century, only reached a limited audience or did not go into the details of Leonardo's inventions.

Reti drew a parallel between several of Leonardo's drawings on antifriction devices and the suspension of the bell in Metz, which he knew from Poncelet's treatise on industrial mechanics (1839) [18][1] (figure 1). Jean-Victor Poncelet (1788–1867) was a graduate of the French *École polytechnique* and from 1825 a professor at the *École d'application de l'artillerie et du génie* in Metz. It is however not certain that Poncelet had a first hand knowledge of the cathedral bell, as we will see later.

Moreover, Reti noticed that Leupold had given a similar representation in his *Theatrum* (1724) [12], albeit without mentioning the cathedral of Metz (figure 1).

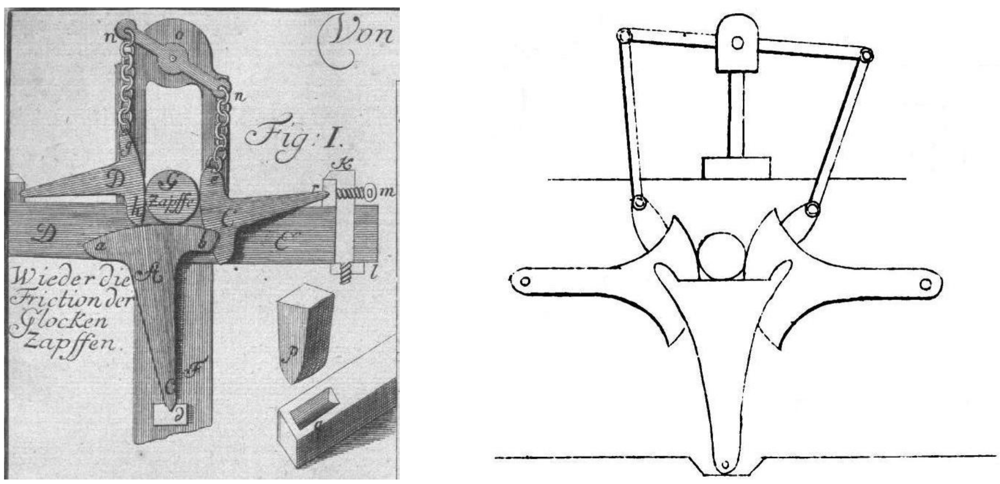

Figure 1: Leupold's (1724) and Poncelet (1839)'s figures [12, 18].

Although neither Leupold, nor Poncelet mention Leonardo, Reti was quick to consider that the Metz engineers had borrowed from Leonardo, because one of the constructions given by Leonardo (figure 2) bore some similarities with those described by Leupold and Poncelet. Around 1970, Reti tried to examine directly the suspension of the bell, but he was not allowed to for safety reasons. However, Ludolf von Mackensen, who was

[1] Reti writes that Poncelet's figure was published in 1845, and although this is true, it is not the first publication by Poncelet on this topic. Poncelet's figure was reprinted in later editions of his treatise and in other books on mechanics.

involved in the German translation of the *Codex Madrid*, was able to obtain an access and could confirm the similarities of the constructions.

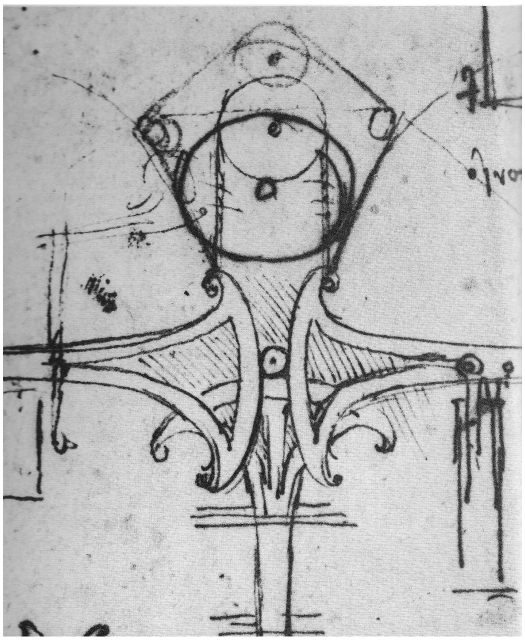

Figure 2: One of Leonardo's drawings in the *Codex Atlanticus*.

Now, even without an examination of the actual suspension, it should be observed that the three figures are far from describing the same constructions. All three figures describe the suspension of the pivots of a bell, and these pivots rotate with rolling (and not gliding) friction on three sectors, two being horizontal, and one being vertical. The entire weight of the bell rests on the vertical sector, whereas the two other sectors serve the purpose of maintaining the horizontal position of the pivots, and at the same time avoid any gliding friction.

Leupold shows the horizontal sectors suspended by chains, whereas Poncelet has connecting rods. Leonardo, on the other hand, seems to use ropes, and describes at least three different ways to conduct the ropes around pulleys. Consequently, Leonardo's scheme is much closer to that shown by Leupold than to the construction described by Poncelet. The actual construction (figure 3) is close, but not identical, to that given by Poncelet.

These differences do not seem to have been highlighted earlier, each author having been quick to state that "the constructions are absolutely

Figure 3: A view of the current suspension (courtesy: Guy Ciunek)

identical" which isn't true.[2]

Moreover, unknown to Reti was the fact that the suspension of the bell was transformed in 1813. It was the engineer and architect Jean-Pierre Jaunez (1745–1830) [2] who designed the new suspension.[3] The first recent published mention on the 1813 transformation seems to be the one by Brioist in 2008 [4].[4]

The first published technical description of the new suspension seems to be the one by Théodore Olivier in 1828 [14]. Olivier's article was apparently overlooked in recent research, although Brioist [5] mentioned Olivier's later, and slightly more complete description, published in 1847 [15].

[2]In addition, several reconstructions have been made on these assumptions. First, the one commissionned by Reti [19] which is much more a copy of Leupold's construction than of the one in Metz, or even Leonardo's. Second, a more recent reconstruction was made for the museo Leonardiano in Vinci, but this time the reconstruction mimics the current linkage in the cathedral, which is very far from Leonardo's construction. This reconstruction also resulted in a 3D animation by Alexander Neuwahl [6]. We believe that there still is a need to reconstruct the suspension using a more faithful approach to the *Codex Atlanticus*.

[3]We give in the appendix an excerpt of Jaunez' 1813 description of the transformations.

[4]However, in a unpublished report written in 2006 on the clock of the clock tower of the cathedral, we had given a transcription of that part of the 1813 report describing the transformation. This report can be consulted in the architectural office supervising the cathedral.

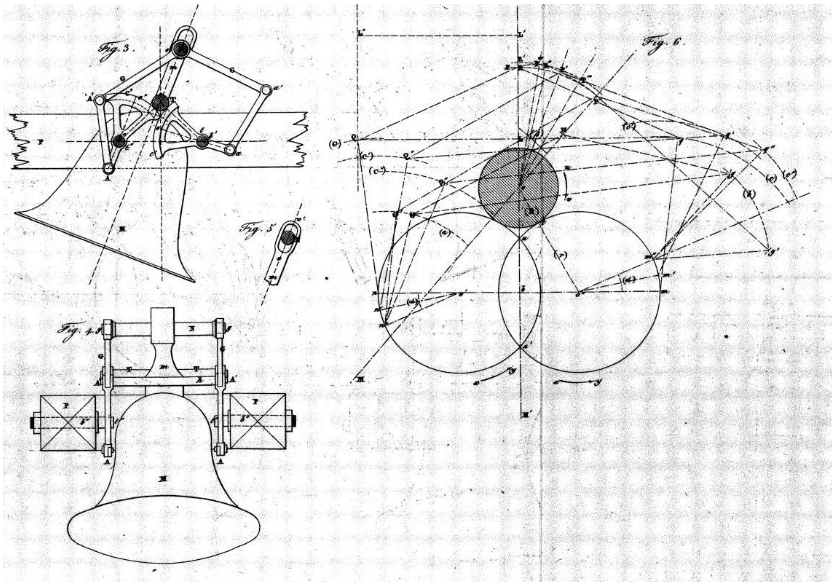

Figure 4: Olivier's drawings published in 1828 [14].

Like Poncelet, Théodore Olivier (1793–1853) was a graduate of the *École polytechnique* and around 1815, he was a student at the *École d'artillerie* of Metz, the very one where Poncelet would be teaching from 1825. In his 1828 article,[5] Olivier states that he first examined the suspension of the bell in 1817, and it is likely that he knew of that bell before Poncelet. It is also likely that Poncelet learned of that bell from Olivier, and not the other way round, as claimed by Brioist [5]. In fact, it is not even sure that Poncelet examined the bell, because he seems to describe the pre-1813 suspension. It is therefore possible that Poncelet only based his 1839 description on that of Olivier, with some additional information on what could have been the old suspension. In any case, Poncelet's drawing is rather faithful to the current suspension, except that he simplified the scale-like lever, perhaps in part following Leupold. As we will see later, Poncelet's drawing comes rather close to Jaunez' description of the old suspension.

There is nothing more in Olivier's 1828 article than in the report published in 1847, except that it strongly suggests Olivier's anteriority over Poncelet.

[5]At the same time as Olivier published his article, Tissot proposed a new solution based on swinging levers [13, 23]. A few years later, Petithomme devised another clever anti-friction solution based on two rolling cylinders [20]. See also Perrey's survey of bell suspensions for other constructions [16].

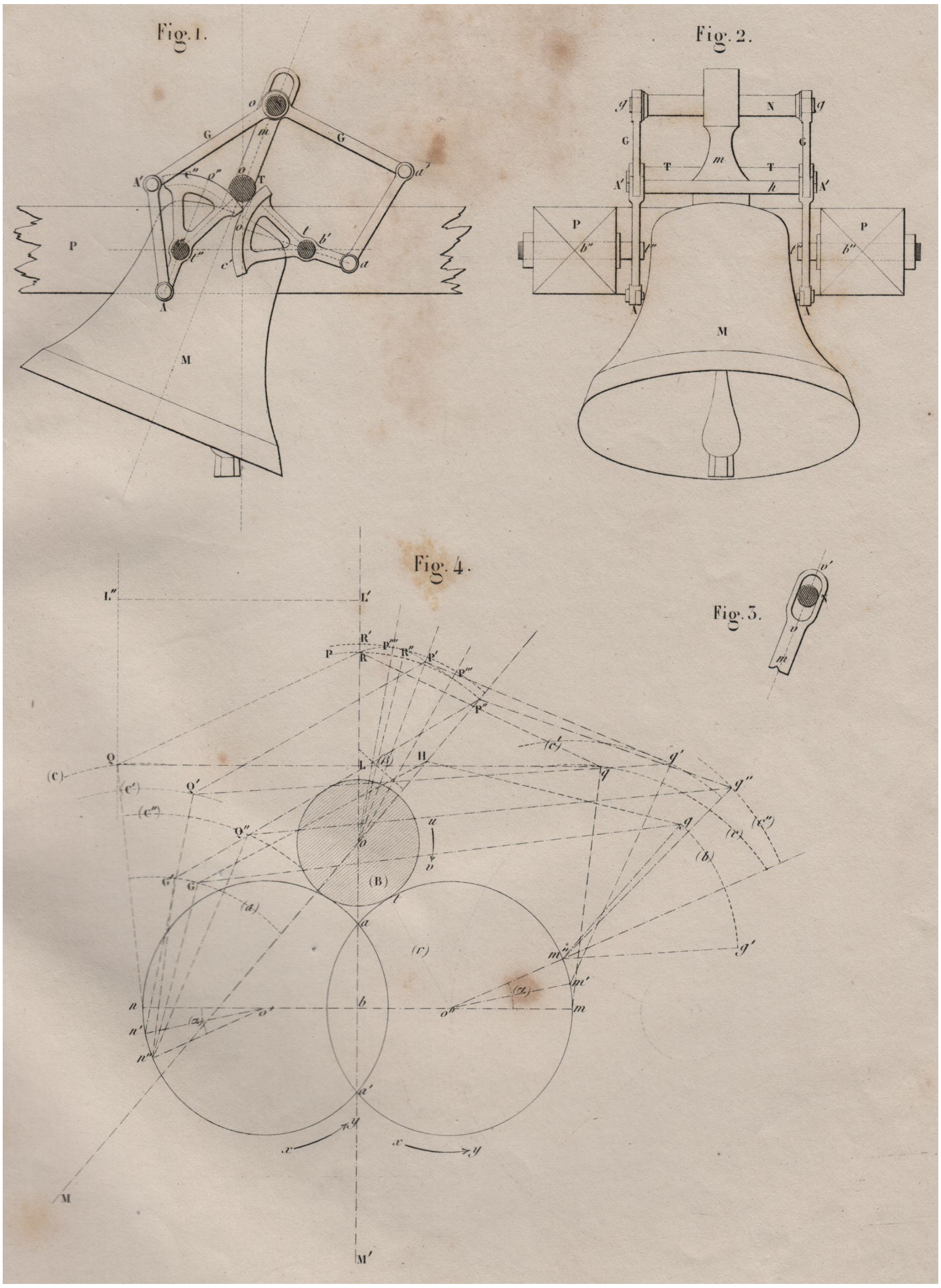

Figure 5: Olivier's drawings published in 1847 [15].

Olivier's 1828 article exhibits a difficulty. In this article, Olivier seems to describe the new suspension designed by Jaunez, but, as remarked by Brioist [5], he did in fact try to imagine what was the earlier suspension. Olivier knew that the old suspension had two side sectors, but he forgot to include the vertical sector mentioned by Jaunez, and his connecting rods were hinged opposite to the sectors, when Jaunez actually tells us that they were very short, and probably positioned like the new ones. Olivier's figure (figure 4) was then reprinted with only minor differences in 1847 (figure 5).

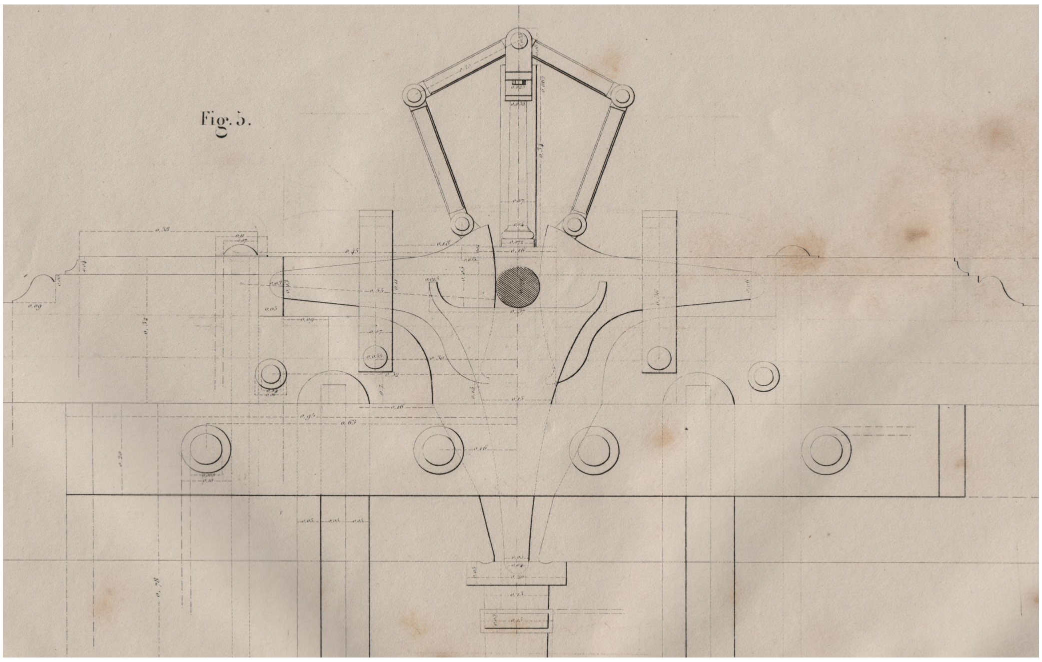

Figure 6: Excerpt of Olivier's drawings published in 1847 [15].

Olivier's focus was on finding solutions using descriptive geometry, and with that perspective, the construction provided by Olivier is pretty much similar to the current one. The analysis given by Olivier applies as well to both constructions. In Olivier's imaginary construction, as well as in the current construction, the two sectors are connected to two rods, which are themselves connected to an angled lever. Olivier's purpose was to find the relative positions of all the elements of this linkage using only graphical tools. In particular, we can see that the angled lever rotates around an axis which is parallel to that of the pivots, but which is not at a constant distance from the pivots, hence the need for an oblong hole.[6]

In order to solve this geometrical problem, Olivier defined a number of points, but eventually resorted to approximations using a triple compass, that is a compass with three legs. In other words, Olivier did not provide an explicit analytical solution to the geometrical problem of finding the configuration of such a linkage. And if he did not do it, this was in part because it is a difficult problem.

The 1847 description only adds one figure to the 1828 description, namely an accurate drawing (with dimensions) of the transformed suspension (figure 6).

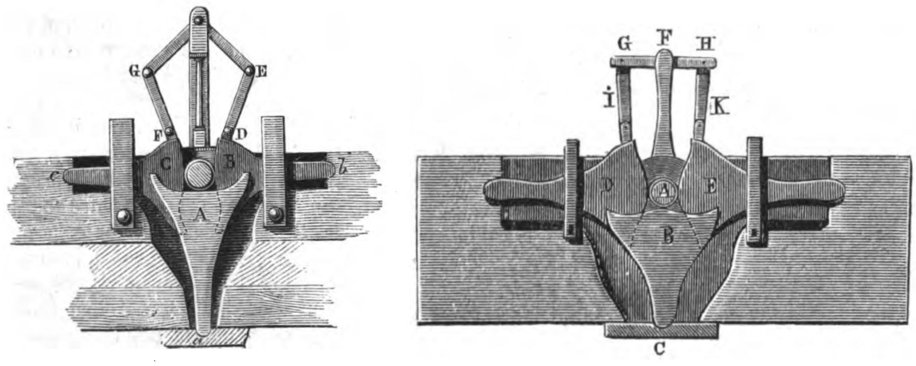

Figure 7: Left: Delaunay's drawing (1851) [8]. Right: Schrader's drawing (1860) [22].

Poncelet's and Olivier's descriptions in turn spawned other descriptions, in particular in Germany. In France, Olivier's figure was adapted by Delaunay in his 1851 treatise of mechanics (figure 7, left), and Delaunay was in turn translated in 1854 in German by Moll [9]. Bauschinger (1861) [1] and Schellen (1862) [21] also used the same figure. But at the same time, we can witness the transmission of Poncelet's drawing into Schrader's treatise (1860) [22] (figure 7, right).

We do also have an account of the older suspension, perhaps devised by François Leprestre [5]. There remains a more recent drawing of that old suspension, probably by Jaunez in 1806.[7] This drawing only shows

[6]The scant photographs of the current suspension do not clearly show whether the center of the angled lever is at a fixed position or not. For good working conditions, it should be moveable, except in the special limit conditions where the path of the lever's axis is nearly a circle centered on T.

[7]That drawing is reproduced in the 2008 exhibition catalogue [4, p. 76] as well as in Brioist's 2010 essay [5]. It is taken from the Metz Archives, shelf mark 1M/b28, but the au-

the two side sectors, but that does not mean that there were no vertical sectors, or no linkage. In fact, in his report written in 1813, Jaunez explicitely mentions that there are side sectors and vertical sectors. He does not write that the side sectors are at right angle, but we believe that the drawing shows that part of the former suspension. Consequently, Jaunez appears to have kept the principles of the old suspension, merely moving the side sectors horizontally, and improving a number of details, including in the linkage.

In other words, the suspension was very similar to that described by Leupold, but with bars instead of chains, and side sectors at right angle. It was also similar to some drawings found in Leonardo's codices. However, as is well known, and stressed by Brioist, Leonardo did not only invent new constructions, but he also described existing constructions which were reported to him by his friends. He was aware of the technical solutions devised in Germany and elsewhere, and such a simple suspension could have been devised by one of many architects. There is no reason to look for a connection with Leonardo.

We can therefore guess that the old primitive suspension was constructed around 1480, and that a more intricate one, similar to the one pictured by Poncelet (or Leupold, but with rods) was devised around 1700, or perhaps even later, before being slightly improved by Jaunez in 1813. It is possible that there was an additional phase where chains or ropes were taking the place of rods. We do not know if the first suspension had vertical sectors, but it is possible.

Once the suspension made use of a scale bar, and ropes or rods, as well as a vertical sector, the friction was then seriously reduced, but not entirely. The use of rods, as well as a moving center for the scale bar, then reduced the friction even further, but as Olivier tells us, sixteen men were still necessary to get the bell ringing [14].

The suspension designed by Jaunez solved the remaining problems by improved rod dimensions, as well as the use of flat bearings for the sector pivots, and improved sectors. After these transformations, which were practically cancelling the gliding friction, ten men became sufficient to get the bell ringing [14].

---

thor gives the incorrect location as "Ouvrages de la Ville, Porfolio number 46, liasse number 6". These archives also contain the drawing of the bell reproduced in [4, p. 74]. Brioist also reproduces one page of Jaunez' report which is found under shelf mark 1M/b40 (formerly 1M/b39). Note that the 1758 report reproduced in [4, p. 74] is located under shelf mark DD37, and not at the location given by Brioist. Most of the archives on the Mutte bell and clock are found in the Metz Archives, under shelf marks DD20, DD37 and in the series 1M. There is also a ca. 1900 drawing of the suspension under shelf mark 9Fi1.585.

Nowadays, these solutions are all made obsolete by ball bearings, and this explains that most ancient bell suspensions have disappeared. It is therefore all the more fortunate that the 1813 suspension was kept during the recent restoration.

3 The study of the linkages

3.1 The development of the suspension linkage

If the primitive suspension had no ropes or linkages, it is likely that someone understood that the sectors would sometimes not move as they should have moved, and eventually the pivots of the bell would pull the sectors instead of merely rolling over them, thereby seriously wearing them out.

An idea that then naturally comes to mind is either that of Leupold, or that of Leonardo, namely to have some *aid* in raising a sector while the other one moves down, and conversely. That simple solution is provided by Leupold's chains, or by Leonardo's ropes (or chains, it does not matter). Leupold had to use chains or ropes, and could not use connecting rods, but this may have been accidental. If Leupold had used connecting rods, he would not have been able to avoid gliding friction, merely because the center of nn (figure 1) can't be at a fixed position with respect to the bell. But with the use of chains, there is no certainty that the pivots of the bell will only roll. In particular, there might be cases when a sector should be lowered, and it doesn't get lowered because it is only suspended. One then naturally comes to think of not using chains, but rods.

But once connecting rods are used, we end up with a linkage, and at first sight one could think that although such a construction helps introducing some balance, it does not ensure that each sector is correctly positioned. In fact it does ensure it. Consider figure 8. In this figure, the front pivot of the bell is T and the two sectors pivot around points 1 and 2. The vertical dashed line is the place going through the vertical revolution axis of the bell and through the pivots. When the bell moves towards the left, the sectors rotate counterclockwise, and when it moves towards the right, they rotate clockwise. Points 3 and 4 are rigidly linked to the sectors, but at these positions we have articulations (marked with hollow circles). There are two connecting rods ending at points 5 and 6. Finally, the angled lever $6N5$ is a rigid element, pivoting at N. The angle between $(N6)$ and $(N5)$ is constant, and N is always in the bell's vertical plane (dashed). (N is in fact an axis, but we consider a vertical section.) Given the positions of points 3 and 4, points 5 and 6 lie on circles. (These are not the curves

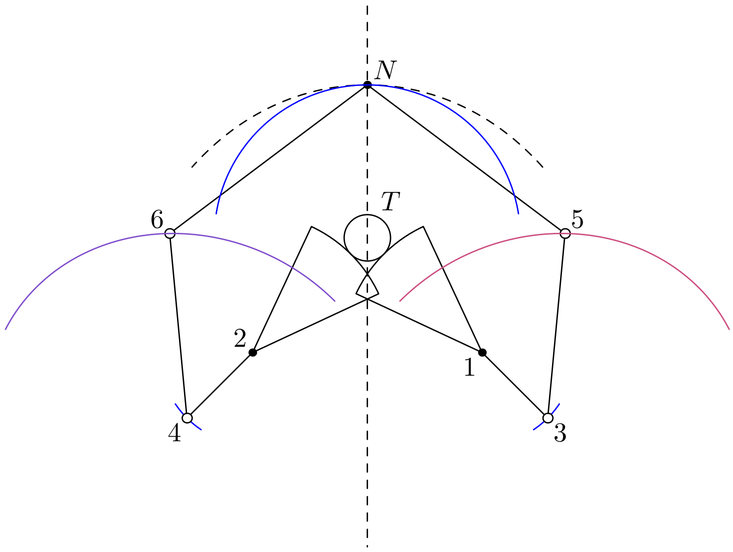

Figure 8: General configuration of the suspension linkage.

shown on the figure, which are in fact the paths of all positions for points 5 and 6.) The problem is therefore to find point N such that the intersections of the circles having as radius the lengths of the arms with the two circles centered on points 3 and 4 provide points 5 and 6 such that the angle between $(N6)$ and $(N5)$ is the sought one. Olivier did achieve this with a triple compass, but the position of N can also be obtained numerically by an iterative process. Given the positions of points 3 and 4, there is only one solution for N, or none, at least in a certain interval. It is easy to see that this linkage can not guarantee that there is no gliding friction, merely because the sectors could be made to turn without the bell moving, and we would still find a solution for N. However, this linkage is a solution to the use of connecting rods, and it shows that it is feasible. It is more likely that there is no gliding friction at the bell pivots with this solution than with Leupold's or Leonardo's solutions.

Eventually came the idea of putting the sectors on horizontal arms, thereby cancelling most of the friction on these sectors, but this made it necessary to add a third sector in case there had been none. The third sector however had to have a limited amplitude, and this could be achieved by raised ends. Such a sector would naturally confine itself in the correct interval. Finally, it should be noted that the vertical sector has no incidence on the determination of the position of point N.

3.2 Characterizing and modeling a linkage

A linkage of the type shown in figure 8 can be characterized by a number of parameters. Both linkages given by Olivier in 1847 are actually particular cases of a more general linkage, where the positions of the axes 1 and 2 may vary, as well as the lengths of the various segments and rods, and the positions of points 3 and 4 at rest. We can take the radius of pivot T equal to 1, and derive all other positions from only a few parameters. Let α be the angle of point 1 with respect to the origin, set at the center of the bell pivots. The radius of the sectors is r, the distance of 1 to the origin is a (and therefore $r + 1 = a$), that of 1 to 3 is b, that of 3 to 5 is c, and that of 5 to N is d. Moreover, the position of 3 with respect to 1 at mid-position is given by the angle β, the angle of the angled lever is γ and the swinging angle of the bell is δ. A certain linkage is therefore characterized by the seven parameters r, b, c, d, α, β, γ.

Using complex numbers, we have the equations:

$$z_1 = (r + 1)e^{-i\alpha} \tag{1}$$
$$z_2 = (r + 1)e^{i(\pi+\alpha)} \tag{2}$$
$$z_3 = z_1 + be^{i(\beta-r\delta)} \tag{3}$$
$$z_4 = z_2 + be^{i(\pi-\beta-r\delta)} \tag{4}$$

Given the unknown δ, the purpose is to find the points 5, 6 and N, using the equations:

$$|z_3z_5| = |z_4z_6| = c \tag{5}$$
$$|z_6z_N| = |z_5z_N| = d \tag{6}$$
$$z_5 - z_N = (z_6 - z_N)e^{i\gamma} \tag{7}$$

It does not seem easy to find simple expressions for z_N as a function of δ, but iterative methods can be used to solve these equations numerically.

3.3 Classification of linkages

The seven parameters determining this family of linkages give rise to a variety of configurations. These configurations differ in various ways, in particular in the amplitude of the swing. But another interesting feature is the path described by point N. As observed by Olivier, N does not describe a circle centered on the bell pivots. In figure 8, the path of N

is shown by a dashed curve, whereas the blue arc is a portion of a circle centered on the pivot T. Figure 9 shows a more extreme position of the same linkage, where the bell has swung by 68 degrees from the vertical. Of course, in practice that configuration would need to be adapted, because the angled lever can't pass through the axis of the bell pivots. However, the angled lever could be made of a different shape, more curved, and still retain the same properties of the linkage.

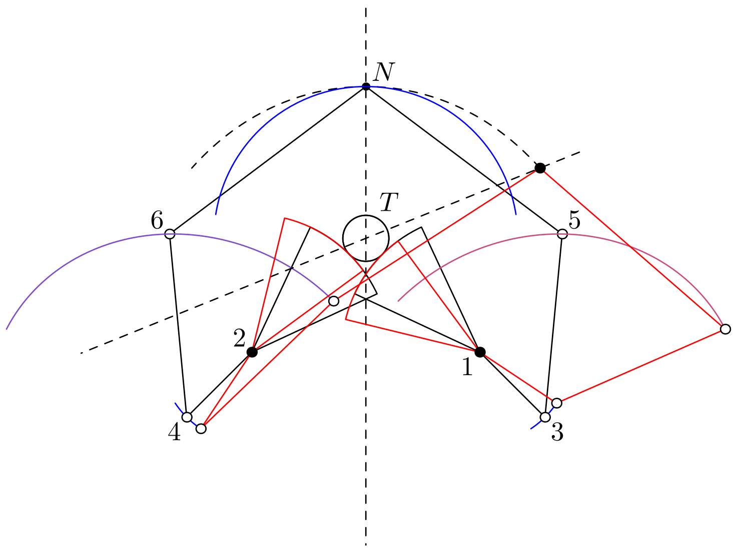

Figure 9: Two configurations of the same linkage. The paths of points 3 and 4 are very small arcs, but those of points 5 and 6, are curves of a much greater amplitude.

With certain configurations, the bell can swing 90 degrees on each side of the vertical, for instance in that given in figure 10. This construction would also have to be adapted in practice.

Figure 11 then shows that the actual path of N, although not a circle centered on T, still is nearly circular.

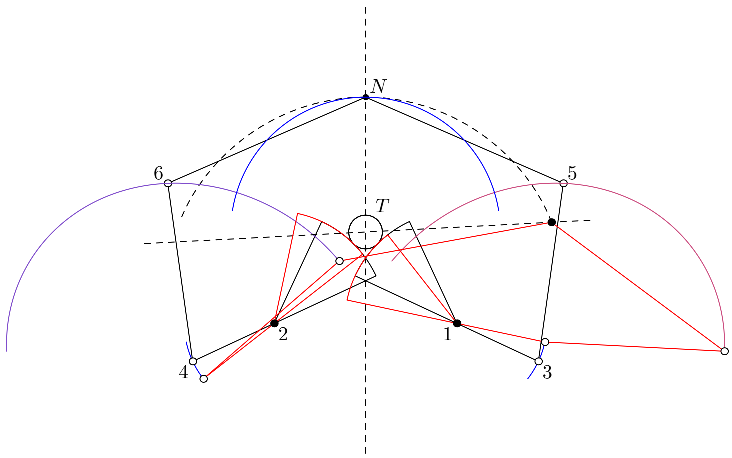

Figure 10: A configuration slightly different from the supposedly old one given by Olivier.

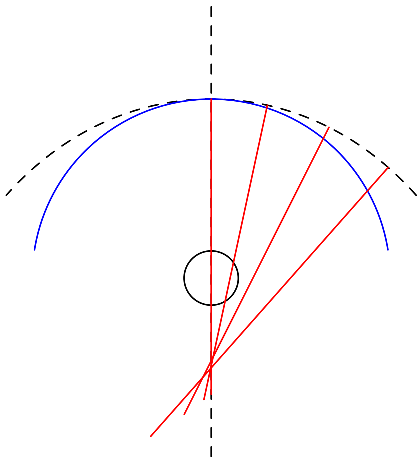

Figure 11: The normals to the path of point N very nearly intersect at one point.

The two previous linkages had as a common feature that the path of N was lying *outside* of a circle centered on T. But this is not always the case. Figure 12 shows the current linkage, as drawn by Olivier in 1847. We have superimposed two configurations, the one at rest and a extremal one. This time, point N describes a curve which lies *inside* a circle centered at T.

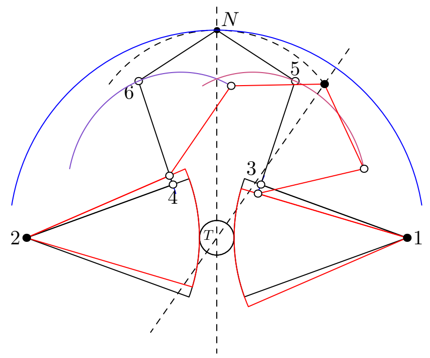

Figure 12: The current linkage, as given by Olivier.

Finally, figure 13 shows yet another configuration, where the path of N almost coincides with a circle centered at T.

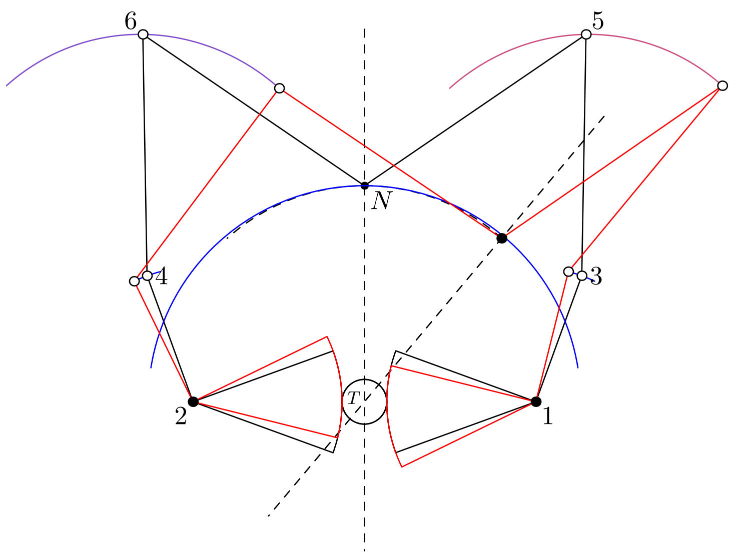

Figure 13: A linkage intermediate between the (supposedly) old and new ones, with a N-path at nearly constant distance from the bell rotation axis.

Appendix: Excerpt of Jaunez' memoir on the bell (18 juillet 1813)

Mémoire[8] Sur la Cloche MUTTE
fondue le 15 Juillet 1605

en Juin 1813 la cloche Mutte etoit devenue si difficile a Sonner, qu'on s'est enfin décidé à la reparer.

La premiere operation à faire etait de la soulever pour parvenir à demonter ses ferremens et à reconnoitre leurs défauts ; il importoit donc de scavoir le poids de cette cloche, pour employer les moyens suffisants et faciles à son soulevement.

D'après un ancien Etat trouvé dans les archives de la ville ; Cette Cloche devait pêser 21887^{L} Ce qui se rapporte au tarif des fondeurs ; car cette cloche ayant six pouces trois lignes de bord, elle doit pêser de même[9] 21840^{L} ; en effet $8^3 : 75^3 :: 26^{\mathrm{L}},5 : x / x = 21840^{\mathrm{L}}$.

Pour soulever la Mutte d'un pied de hauteur, on s'y est pris de la maniere suivante :

on a posé sous la cloche deux traverses B (planches) de six pieds de longueur sur 9 à 12 pouces de grosseur ; Ces Traverses ont été mises à fleur de la Baille de la Cloche ; par dessus Ces mêmes Traverses on a encore posé deux longerons A qui avoient chacun 12 pieds de longueur sur 9 à 10 pouces de grosseur ; tous ces Bois etoient de chêne et de Brin.

a un bout des Longerons on a appliqué un verin Composé de quatre vis, d'une Semelle et de deux chapeaux ou ecroux ; en Tournant les quatre vis à la fois avec des pinces qui avoient quatre pieds de longueur, on a soulevé les deux Longerons et la cloche assez haut pour poser un madrier de quatre pouces d'Epaisseur par dessus la Traverse B du Côté du verin ; ensuite on a porté le même Verin à l'autre extremité des Longerons et Cette operation recommencée huit fois de Suite ; on est parvenu à Soulever la Mutte a 12 pouces de hauteur Sans aucune peine n'y difficulté.

Données

[8]Archives municipales de Metz, 1M/b40 (= 1M/b39 at least until 2005). There are two copies of this memoir, and we have transcribed the one which appears to be a draft of the other. For our purpose, namely the description of the linkages, there are only small differences between the two versions. Note that Brioist made a partial transcription of the better version [5, p. 56]. In our transcription, we have been faithful to the original spelling and capitalizing. The figures mentioned in this memoir are not extant.

[9]Jaunez seems to consider another bell having a rim of 8 *lignes* and weighing 26.5 *livres*, and to multiply its weight by the cube of the ratio of the rims, 75 being six inches and 3 lines expressed in lines.

Les vis du verin avoient Six pouces de Diametre et de pas Cy . $1^{\mathrm{po}}\ 6^{\mathrm{li}}$
Le Diametre des Bras de Leviers ou des pinces etoit de .... 84^{po}
L'effort des quatre hommes employés à la fois pouvoit être de 100^{L}

Calculs de la force du Verin[10]

$84^{\mathrm{po}} \times 3\,1/7 = 264^{\mathrm{po}}$
$264^{\mathrm{po}} \times 100^{\mathrm{L}} = 1^{\mathrm{po}}.1/2 \times x$
$x = 30933^{\mathrm{L}}$

en Supposant que les frottemens détruisent les $2/3$ de cette force (ce dont on a l'experience) il restera encore 10311^{L}.

Les Bras de Levier des Longerons A posés sous la cloche, sont 108^{po} et 42^{po} donc $10311 \times 108 = x \times 42$. $x = 26514^{\mathrm{L}}$ force totale de la Machine, tous les frottements déduits.

La Mutte ayant eté soulevée de douze pouces audessus des Segments de Cercle Sur lesquels Ses eguilles[11] tournaient, on est parvenu à tout démonter et à reconnoitre que les mêmes eguilles etoient d'une seule pièce ; que le Tourillon du Côté de l'hotel de ville etoit usé de plus de Six lignes ainsi que les Segments de Cercle Lateraux.

on n'a point eté etonné de ce fait, quand on s'est aperçu que la Construction de ce mouvement etoit aussi vicieuse que l'idée en etoit ingenieuse, Si on eut Sceu l'executer et la rendre Comme l'inventeur a dû la Concevoir.

Les Segments verticaux (fig. 1re) portent une echancrure pour Recevoir les Tourillons, en outre ils sont Terminés de niveau Sans Courbure, en sorte que de cette maniere, il est impossible qu'ils puissent avoir aucun mouvement ; Ce defaut est le comble de l'ignorance et de l'impéritie des ouvriers qui ont executé ce travail ou de ceux qui l'ont dirigé.

Les Segments Lateraux ont à peu près le même defaut que les precedents ; le Balancier posé au dessus S'oppose à leur mouvement qui devroit être d'environ 5 pouces 2 lignes quand la cloche parcoure un demi Cercle ; en sorte qu'il devient un obstacle aulieu d'être à son avantage ; on peut donc dire hardiment que le mecanisme fait pour diminuer les frottemens, les accumule et les augmente de toute maniere ; qu'il eut été plus Simple,

[10] In these computations, Jaunez computes the work of the torque of four men over the circumference, the levers having a diameter of 84 inches and 3.1/7 being an approximation of π. This work is then made equal to the work of the screw whose pitch is 1.5 inches, and assuming that two thirds of the work is lost in friction, Jaunez deduces that one turn will move about 10000 pounds, although we fail to see how he obtained his value of 30933 pounds. This force is then used in levers multiplying the strength by a ratio 108/42, which is then sufficient to raise the bell.

[11] These are the pivots of the suspension.

dans Cet etat de chose, de poser Cette Cloche sur des Crapaudines de Cuivre, plustôt que de presenter l'apareil d'une machine Compliquée qui devient en pure perte et Contraire au mouvement.

à tous ces défauts de l'ancienne Construction il faut encore ajouter Celui des Trois Crapaudines dont les coches pour recevoir les pivots des segments, etoient taillées en demi Cercle, au lieu d'être en ligne droite ; delà il auroit resulté, Si les Segments Lateraux avoient eû leur mouvement naturel, que leurs rayons S'alongeaient et diminuaient alternativement, la Compression des eguilles de la Mutte entre les deux mêmes Segments, auroit varié de même, Ce qui auroit eté bien contraire au mouvement regulier de la Cloche, qui exige que Cette Compression Soit constamment Egale, mais Ce qui ne peut arriver que lorsque tous les rayons des Segments Lateraux Se trouveront toujours egaux à chaque point de leur marche ; que la Courbe de leur pivot Sera Circulaire et enfin Celle de leur bord Supérieur une Cycloïde. avec Ce défaut plus grand qu'on ne pense, nous Comprendrons encore Celui des frottements qu'il occasionne et qui ne devroient pas avoir Lieu, Si chaque partie avoit la forme qui lui Convient.

on verra par la figure 2^e^ les changements que nous avons imaginé pour donner à cette Construction tout le mérite dont elle est susceptible.

Les deux Segments Lateraux n'ont aucune tendance à se deranger, etant soutenus par un Balancier qui rend leur mouvement egal et alternatif ; il n'en est pas de même des Segments verticaux qui supportent la Cloche ; Ces Segments dont la Courbure Superieure est tracée par un rayon triple de leur hauteur, aulieu d'être tracée par un rayon egal à cette même hauteur selon l'ordre naturel, leur donne une tendance à se tenir verticalement ; tandis que par la derniere maniere ils pourroient se jetter à droite ou à gauche et dans cette derniere position, il leur seroit impossible de se relever ny de se remettre d'applomb.

il est bon d'observer que par la Courbure qu'ont les Segments verticaux, la cloche à chaque balancement, est obligée de s'elever insensiblement, comme si ses tourillons rouloient sur des plans inclinés peu rapides à la verité, mais assez pour empecher les Segments de se jetter de coté ; Car par la loi de la gravitation, la cloche doit tendre continuellement plustot à descendre qu'a monter et par cette raison ramener ces segments dans leur aplomb, qui est la position ou la Mutte est le moins elevée.

Les tringles qui lient les segments lateraux au balancier, ont environ quinze pouces de longueur ; Leur direction est perpendiculaire a la ligne qui passe par les centres de mouvements, afin que les arcs que décrivent ce balancier et ces segments, soient dans une même direction et rendent les mouvements de ces mêmes segments egaux et reguliers, pour eviter le grand défaut de l'ancienne construction, ou les pareilles tringles n'avoient que trois pouces et demi de longueur ; aussi retenoient-elles la marche des segments auxquels elles etoient attachées et occasionnoient-elles un grand frottement en cette partie.

nous pouvons assurer que de tous les moyens que nous avons cherché pour assujetir le mouvement des segments verticaux et empecher leur deversement ; le dernier comme le plus simple, le plus facile a executer et enfin, celui le moins exposé à se deranger, a merité la preference ; aussi l'experience a confirmé notre opinion.

on saura donc que non seulement nous avons diminué de plus (ici un blanc) La peine qu'on avoit pour sonner cette cloche, mais encore qu'en rendant son mouvement plus regulier et sans balotement, nous avons diminué les secousses dans le beffroy et dans la tour ou il est monté ; que par ce moyen nous reculerons la ruine de cette tour et de la flèche qui la couronne, mais qui est inevitable avec le tems, mais aussi qui sera dévancée par le choc et l'ebranlement qu'ils eprouvent chaque fois qu'on sonne la Mutte.

en effet si le poids de cette cloche en repos est de 22420 y compris son battant, il augmentera de beaucoup lorsqu'elle sera en mouvement ; car si son centre de gravité est quatre pieds en contrebas du centre de mouvement, ce qui a eté apprecié d'après son profil ; ce centre de gravité en parcourant un demi cercle a acquis une vitesse egale à celle qu'il eut eû s'il etoit tombé d'une pareille hauteur de quatre pieds ; mais par les principes de la mecanique, la force centrifuge, est à la pesanteur du corps, comme la hauteur due à la vitesse, est à la moitié du rayon ; donc $\frac{22420 \times 4^{\text{pi}}}{2^{\text{pi}}} = 44840^{\text{L}}$ sera le poids agissant sur les eguilles ou sur le beffroi quand la cloche sera en plein mouvement ; que l'on actuellement de l'effet que peut produire un pareil poids elevé à cent cinquante pieds de hauteur ou attaché au bout d'un semblable levier.

C'est encore ici le cas d'observer que c'est avec beaucoup de discernement qu'on a disposé le beffroi de la Mutte, de maniere à faire jouer cette cloche dans le sens de la longueur de la nef et que si son mouvem$^{\text{t}}$ eut eté dans le sens opposé, c'est a dire transversalement à cette nef, ainsi que sonne la cloche marie dans le clocher de bois ; à coup sûr la cathedrale n'existeroit plus, ou la Mutte auroit eté interdite depuis son installation ; car c'est à la cloche marie qu'on doit attribuer la chute de l'arc doubleau dans la voute de la nef qui correspond entre les deux tours ; c'est aussi cette même cloche qui, quand on la met en mouvement communique un ebranlement ou une oscillation generale à la nef, à la tour de Mutte, et à sa flèche qui est d'environ trois pouces mesurée sur la platteforme du guet ; que serait-ce si la Mutte avoit la même position que Marie, puisque leur effet seroit en raison de leur poids et peut être double l'un de l'autre ; cette observation doit faire reflechir sur la mauvaise direction d'une partie des cloches placées dans la tour opposée à celle de Mutte.

enfin nous terminerons par dire que le levier qui correspond au milieu de la hauteur de la Mutte n'est pas plus avantageux pour mettre cette cloche en mouvement dans le premier moment, que celui placé audessus du mouton, parceque leurs bras sont egaux.

mais lorsque la Mutte est en mouvement, le levier inferieur a un grand avantage sur le superieur, parceque cette cloche etant par exemple dans une position horizontale, le bras de ce dernier levier est alors opposé à la force impulsive de la cloche tandis que le bras du levier inferieur a quatre pieds de longueur c'est à dire qu'il est egal à la distance qui se trouve entre les Eguilles et sa position ; de maniere que ce bras de quatre pieds de longueur produit une difference considerable qui augmente de beaucoup la force des sonneurs.

(. . .)

Rédigé par le soussigné ingénieur de la ville le 18 Juillet 1813

(signé : Jaunez)

References

[1] Johann Bauschinger. *Die Schule der Mechanik*. München : R. Oldenbourg, 1861.

[2] Émile-Auguste Bégin. *Biographie de la Moselle*, volume 2. Metz: Verronnais, 1830.

[3] Émile-Auguste Bégin. *Histoire & description pittoresque de la cathédrale de Metz, des églises adjacentes & collégiales*. Metz: Verronnais, 1840, 1842. [2 volumes].

[4] Pascal Brioist, editor. *Les rêves mécaniques de Léonard de Vinci : ... des croquis aux machines* . Rombas: Office municipal de la culture, 2008. [exhibition in Rombas, 20 January 2008–20 April 2008, a review of the catalogue was published by Martine Mille in *Documents pour l'histoire des techniques*, volume 15, 2008, pp. 250–252.].

[5] Pascal Brioist. The dissemination of know how: The case of the bell La Mutte in the city of Metz. In Robert Kretzschmar and Sönke Lorenz, editors, *Leonardo da Vinci und Heinrich Schickhardt : Zum Transfer technischen Wissens im vormodernen Europa*, pages 48–57. Stuttgart: Landesarchiv Baden-Württemberg, 2010.

[6] Pascal Brioist. Les transferts de savoir-faire. *Documentation photographique*, 8079:60–61, 2011.

[7] Augustin Calmet. *Histoire ecclésiastique et civile de Lorraine, etc.*, volume 3. Nancy: Jean-Baptiste Cusson, 1728. [see on column 61 for the Mutte bell].

[8] Charles Delaunay. *Cours élémentaire de mécanique théorique et appliquée etc.* Paris: Langlois & Leclercq, 1851.

[9] Charles Delaunay. *Die reine und angewandte Elementar-Mechanik*. Braunschweig: Friedrich Vieweg und Sohn, 1854. [translation of Delaunay's treatise by C. L. Moll].

[10] Anne-Laure Gerbert, Christophe Bottineau, and Éric Brottier. La cathédrale Saint-Étienne à Metz, la restauration de la tour de Mutte. *Monumental*, semestriel 2:52–57, 2015.

[11] Victor Jacob. Histoire de la tour et de la cloche de mutte. *L'Austrasie, revue de Metz et de Lorraine*, 11:195–226, 255–286, 373–404, 458–472, 501–519, 560–567, 623–637, 1863.

[12] Jacob Leupold. *Theatrum machinarum generale*. Leipzig: Christoph Zunkel, 1724.

[13] François-Emmanuel Molard. Rapport sur un moyen de supprimer le frottement des axes dans les grandes machines. *Bulletin de la société d'encouragement pour l'industrie nationale*, 27:253–254 (and plate 366), August 1828.

[14] Théodore Olivier. Note sur un mécanisme servant de support aux tourillons de la grosse cloche de la cathédrale de Metz. *Bulletin de la société d'encouragement pour l'industrie nationale*, 27:255–259 (and plate 366), August 1828.

[15] Théodore Olivier. *Applications de la géométrie descriptive aux ombres, à la perspective, à la gnomonique et aux engrenages*. Paris: Carilian-Gœury & Victor Dalmont, 1847. [2 volumes, text and plates].

[16] Édouard Perrey. Montage des cloches et construction des beffrois. *Revue générale de l'architecture et des travaux publics*, 13:318–330, 365–377, 1855.

[17] Jean-Paul Philips. *De cloches en cloches — Du pays messin à Thionville et à la Nied*. Metz: Éditions des Paraiges, 2011. [pp. 43–49 on the Mutte bell and its suspension].

[18] Jean-Victor Poncelet. *Mécanique industrielle exposant les principes de statique et de la dynamique, les organes mécaniques et les moteurs*. Liége : A. Leroux et comp., 1839. [second part].

[19] Ladislao Reti, editor. *The unknown Leonardo*. New York: McGraw-Hill Book Company, 1974.

[20] Jacques-François Saulnier. Rapport sur un système de suspension des cloches, par M. Petithomme. *Bulletin de la société d'encouragement pour l'industrie nationale*, 47:350–352 (and plate 1067), July 1848. [see also page 343].

[21] Heinrich Schellen. *Die Schule der Elementar-Mechanik und Maschinenlehre für den Selbstunterricht etc.* Braunschweig: Friedrich Vieweg und Sohn, 1862. [first part].

[22] Wilhelm Schrader. *Elemente der Mechanik und Maschinenlehre für technische Lehranstalten und zum Selbststudium. Erster Theil : Geomechanik*. Halle: Schroedel & Simon, 1860. [first of two volumes; the second one was published in 1862].

[23] F. Tissot. Moyen de remplacer les galets et application aux cloches. *Bulletin de la société d'encouragement pour l'industrie nationale*, 28:213, June 1829. [probably Ferréol Tissot].